AD-A067 891 COAST GUARD RESEARCH AND DEVELOPMENT CENTER GROTON CONN F/G 10/2
COAST GUARD MARINE EXPOSURE FACILITIES FOR NATURALLY AGING SOLA--ETC(U)
OCT 78 F GIOVANE

UNCLASSIFIED CGR/DC-20/78 USCG-D-18-79 NL

1 OF 1
AD A067891

END
DATE FILMED
6 -79
DDC

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
USCG-D-18-79		

4. Title and Subtitle
COAST GUARD MARINE EXPOSURE FACILITIES FOR NATURALLY AGING SOLAR PHOTOVOLTAIC MODULES.

5. Report Date
Oct 1978

6. Performing Organization Code

7. Author(s)
Frank Giovane

8. Performing Organization Report No.
CGR&DC-20/78

9. Performing Organization Name and Address
United States Coast Guard
Research and Development Center
Avery Point
Groton, CT 06340

10. Work Unit No. (TRAIS)

11. Contract or Grant No.

12. Sponsoring Agency Name and Address
Department of Transportation
U.S. Coast Guard
Office of Research and Development
Washington, DC 20590

13. Type of Report and Period Covered
Final Report

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

A program to evaluate photovoltaics in the marine environment has been undertaken by the Coast Guard Research and Development Center. This effort aims at development of suitable screening and qualification tests for solar photovoltaic energy systems intended for powering low voltage lighted aids to navigation. To assist in the attainment of these goals, two facilities have been established in proximity to the sea. One located at Avery Point, Groton, Connecticut, is characteristic of a northern marine climate with frequent frosts and cold winter cycles. The other, located in the south, at CG Station Fort Lauderdale, Dania, Florida, is characteristic of a southern marine climate with no frost cycles and relatively year round constant temperatures. Together, they nominally represent the extremes of climate under which the Coast Guard deploys aids to navigation. The two sites offer the Coast Guard a unique facility from which to access the reliability of solar photovoltaic energy system components in the marine environment, and to generate data essential to determining their cost-reliability relations.

17. Key Words	18. Distribution Statement
Solar Photovoltaic Aids to Navigation	Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED		

Form DOT F 1700.7 (8-72) Reproduction of form and completed page is authorized

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

1.0 INTRODUCTION

Only in the last 20 years has it become practical to convert sunlight directly to electrical energy by the use of photovoltaic properties of semiconductors. Arrays of these semiconductors have been fabricated to power satellites, and their success and reliability in the space environment is well documented. Their use on earth, with its weather, has only just begun, and to date, their terrestrial success has not been universal.

The severity of the earth environment was initially underestimated, and many of the early terrestrial solar photovoltaic devices failed because of corrosion and mechanical breakdown under the changing temperature, pressure, and humidity of earth. Lessons were thus learned, and corrective actions taken which, hopefully, have resulted in the development of more durable solar photovoltaic devices. Further, it now appears that solar photovoltaic energy systems may be a cost-effective and reliable means for powering low-voltage lighted aids to navigation (AN) maintained by the Coast Guard.[1] However, before solar photovoltaics can be accepted into the AN hardware inventory, the relationship of cost-to-reliability must be established. Not until this relationship is determined can the Coast Guard afford to deploy these photovoltaic devices on a large scale.

This determination is difficult. The rapidly changing technology, the complex structure of photovoltaic devices, and the general lack of interest outside the Coast Guard in developing low-cost photovoltaics capable of surviving in the marine environment compound this problem. Thus, it is essential that the reliability of potential cost-effective devices be determined by the Coast Guard in the marine environment.

In the past, tests at the Coast Guard Research and Development Center were directed at evaluating the interaction of solar photovoltaic energy system components. These tests identified only one highly reliable photovoltaic device, a module (CSP14) manufactured by OCLI (Optical Coating Laboratory Incorporated) (present cost approximately $50 per-peak watt[2]). However, practically no knowledge was obtained of the survival potential of other photovoltaic devices, particularly those low-cost devices that might be cost-effective for AN deployment. This failure was due in large measure to the lack of adequate marine testing and, in general, to the limited testing of potentially cost-effective photovoltaics. Since the present cost of modern photovoltaics range from about $25 to $9 per peak-watt[3], and the price can be anticipated to drop to as low as $1 per peak-watt in the near future, more knowledge must be gained about the survivability of these new photovoltaic devices.

In order to remedy past deficiences in testing, a program to evaluate modern and prototype photovoltaics in the marine environment has been undertaken by the Coast Guard Research and Development Center as part of the Energy Sources Project (2705). This effort, embodied as the Natural Environment Exposure Test (NEET)[4], aims at development of a screening, and later a qualification test, for solar photovoltaic devices. To assist in the attainment of these goals, two facilities have been established. One, located in

---

[1,2,3,4]References are given on Page 15.

the northeast, at Avery Point, Groton, Connecticut, is characteristic of a northern marine climate; the other, located in the south, at CG Station Fort Lauderdale, Dania, Florida, is characteristic of a southern marine climate. Together they nominally represent the extremes of climate under which the Coast Guard deploys aids to navigation.

This report describes these facilities in detail, characterizes their environmental conditions, and considers other auxiliary uses for these facilities.

2.0 MARINE EXPOSURE FACILITY

In order to evalute the possible sites at which to locate the exposure facilities, selection criteria were developed. Principal among these were the requirements for:

1. Proximity to the sea, in order to simulate the conditions found on an aid to navigation.

2. Accessibility, in order to expedite installation and inspection, and

3. Security, required to minimize the possibility of vandalism and theft.

In the south, Coast Guard Station Fort Lauderdale satisfied all the major criteria. An alternate site, located at the Coast Guard station at Islamorada, in the Florida Keys, although completely acceptable, was considered less desirable than the Fort Lauderdale station because of its greater distance from the major airports.

In the north, the problem proved less tractable. A site close to the R&D Center was desired, but those sites that were acceptable in terms of security were reachable only by boat. They were consequently rejected. Finally, it was decided that Avery Point, the location of the R&D Center, was the most desirable site for the exposure facility. Avery Point itself is on the grounds of the University of Connecticut. Although this site is not as secure as a manned Coast Guard station, it is heavily patroled, and the local parking restrictions and the rocky coast limits casual access to the Point. The choice of Avery Point as the northern exposure facility has, on the other hand, the paramount advantage of excellent accessibility and a fine exposure to the sea.

2.1 Southern Marine Exposure Facility

The Southern Marine Exposure Facility is located at Coast Guard Station Fort Lauderdale, on the north end of Dania Island. The station is easily accessed by auto, and it is convenient to both the Miami and Fort Lauderdale airports. Figure 2-1 shows the location of the station. The exposure facility is located at the southwest corner of the station's breakwater, at approximately 26°05'N latitude and 80°07'W longitude.

Although the water is shallow in this region of the breakwater, the waves of passing boats on the ICW (Intra-coastal Waterway) and Port Fort Lauderdale keep the sea in proximity to the bulkhead choppy.

The facility was constructed of wood stringers bolted to the station's steel breakwater and to three I-beam piles. A wood deck was built on the stringer so as to provide a convenient work platform. The platform is approximately 26 feet long by 17 feet wide and lies about 2.5 feet above the high water mark on the breakwater. Figure 2-2 shows the platform under construction. For all practical purposes, it can be considered surrounded by water, with access either by walk way, along the top of the south section of the station's breakwater, or by boat, which can be docked alongside the platform.

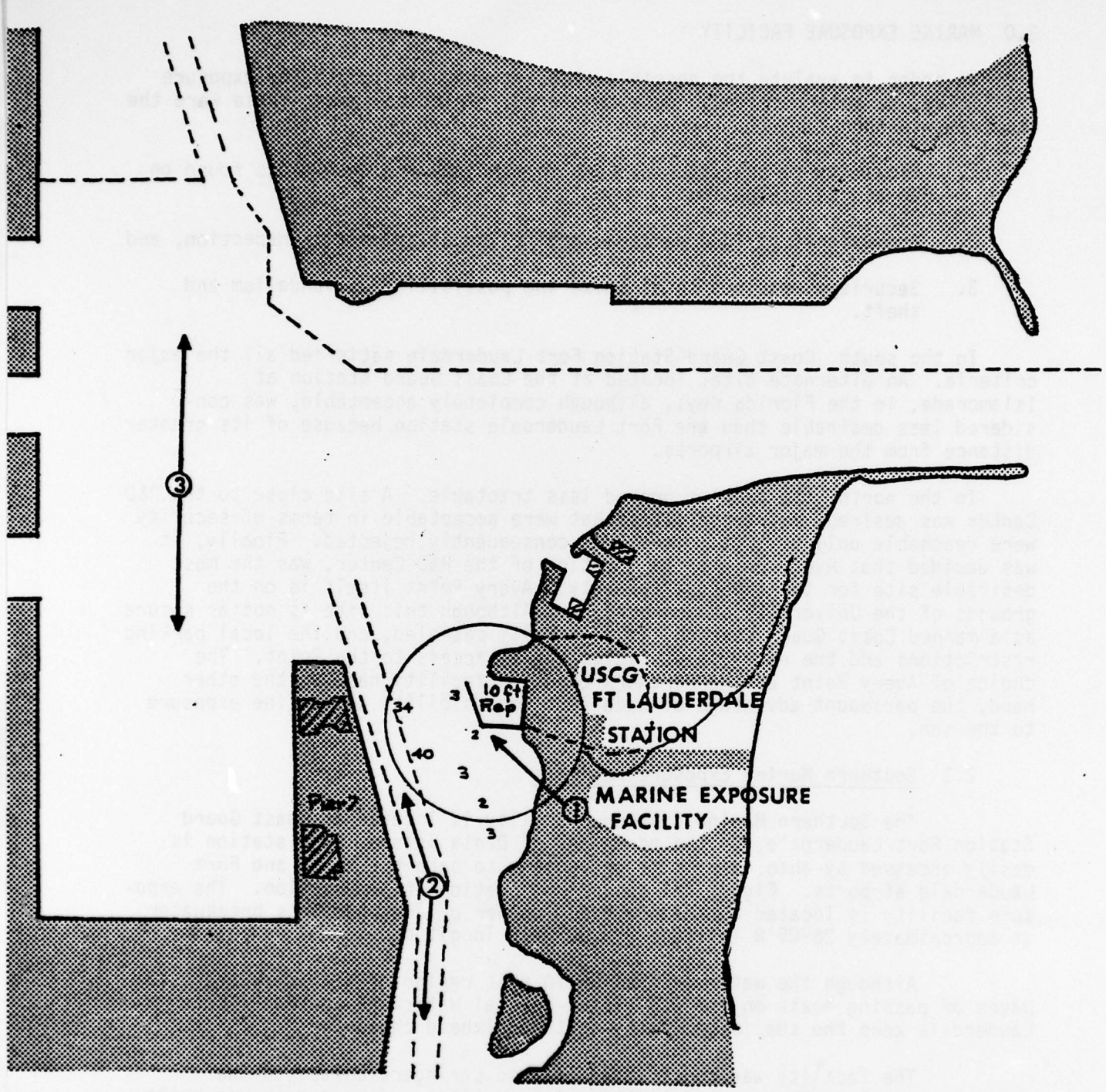

FIGURE 2-1. SOUTHERN MARINE EXPOSURE FACILITY. THE CHART ILLUSTRATES THE LOCATION OF THE EXPOSURE FACILITY ① AT THE SOUTHWEST CORNER OF THE USCG FORT LAUDERDALE STATION BREAKWATER ②, THE INTRA-COASTAL WATERWAY ③, AND THE PORT OF FORT LAUDERDALE. NUMBERS OUTSIDE THE CHANNEL ARE DEPTH AT MEAN LOW WATER IN FEET.

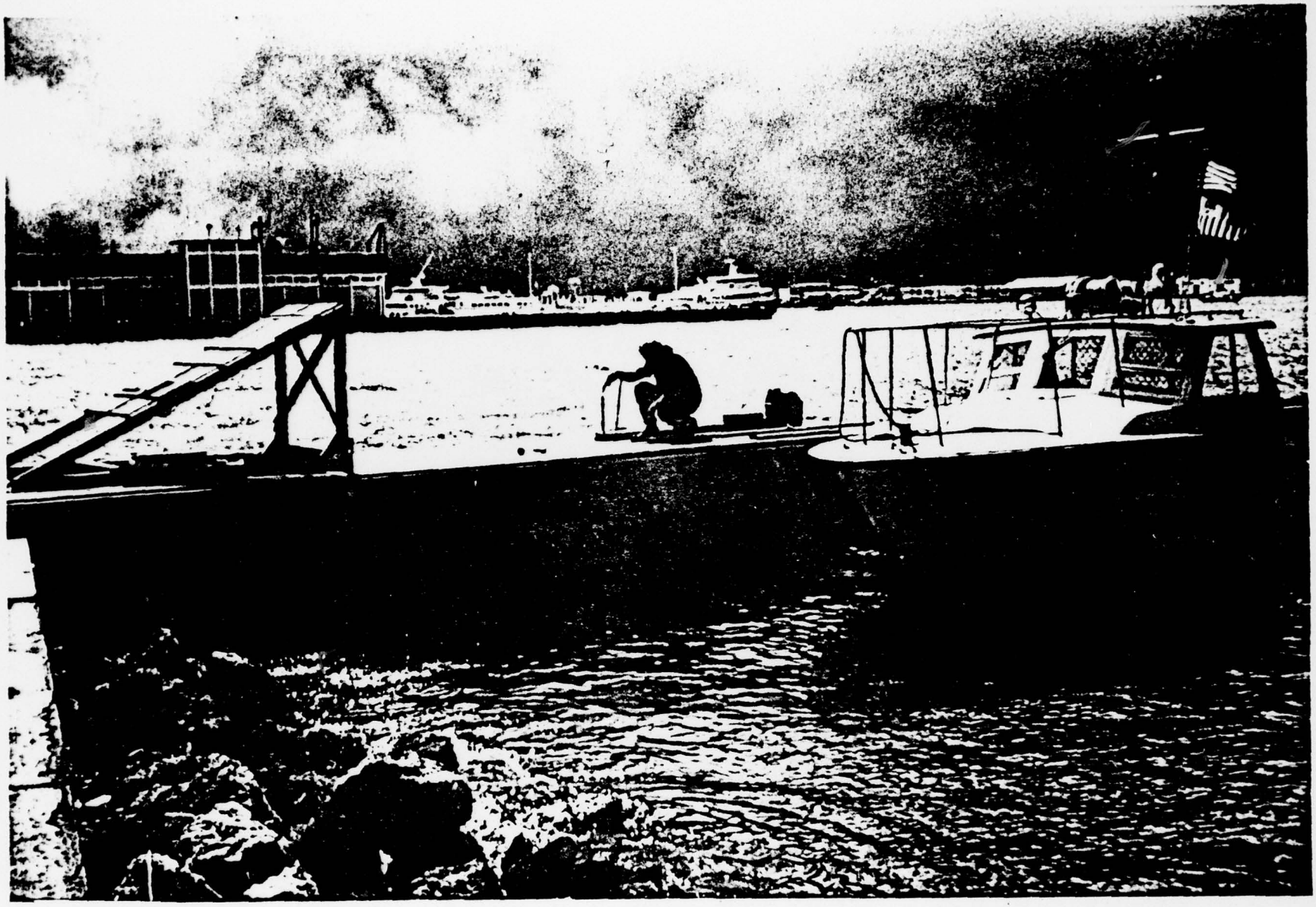

Figure 2-2. Southern Marine Exposure Facility under construction. Only the first mounting stand had been erected at the time of this photograph.

The solar photovoltaic modules under test are mounted on stands. These stands are inclined 20 degrees to the horizon facing south; this is illustrated in Figure 2-3. Three stands were constructed. These measure 120 inches by 48 inches, 120 inches by 56 inches, and 143 inches by 96 inches. They provide about 184 square feet of useable area on which to deploy photovoltaics.

The anticipated climate at the southern marine exposure facility is given in Table 2-1 which is a summary of past meteorological records. The actual climate will be characterized by in-situ measurements using a meteorological instrument package which will monitor solar irradiance, temperature, and humidity. This instrumentation will be deployed during 1979 and will remain at the facility for at least one year.

The modules will be mounted to L-angle beams, which will span the short dimension of the mounting stands (i.e., 48, 56, and 96 inches). The mounting holes will be drilled oversize to allow for differential expansion. In general, the manufacturer provided mounting holes on the modules will be used to fasten the module to the L-beam. However, in those cases where the manufacturer has not provided mounting holes, the modules will be strapped to the L-beam with flat stock or L-beam. Theft-resistant bolts and washers will be used to reduce the possibility of tampering and theft.

Modules will be electrically loaded by means of a resistor whose value will be chosen so that the module output voltage will be 0.375 volts per module cell when illuminated by 100 mw/cm^2.

2.2 Northern Marine Exposure Facility

The Northern Marine Exposure Facility is located at Avery Point, Groton, Connecticut, on the grounds of the University of Connecticut. The facility is located approximately 75 feet east of the abandoned Avery Point Light House at $41^{o}19'N$ latitude and $72^{o}04'W$ longitude. This is illustrated in Figure 2-4.

The concrete piers which form the facility's foundation rest on a rock outcrop to the south of a bulkhead. The rock is usually submerged at high tide, and the base of the photovoltaic mounting area is approximately 2.5 feet above the high water mark on the bulkhead. Figure 2-5 illustrates the concrete piers, the steel posts, and the aluminum beam construction of the facility. The mounting area is inclined 41 degrees from the horizon to the south. In all, the structure is approximately 8 feet by 32 feet at the base and can accomodate up to 340 square feet of solar photovoltaic modules. However, if working spaces are allowed so as to give convenient access to the modules, then the effective capacity is reduced to about 275 square feet.

Access to the structure is by vehicular road, and 100 volts 60 hz power can be made available at the site.

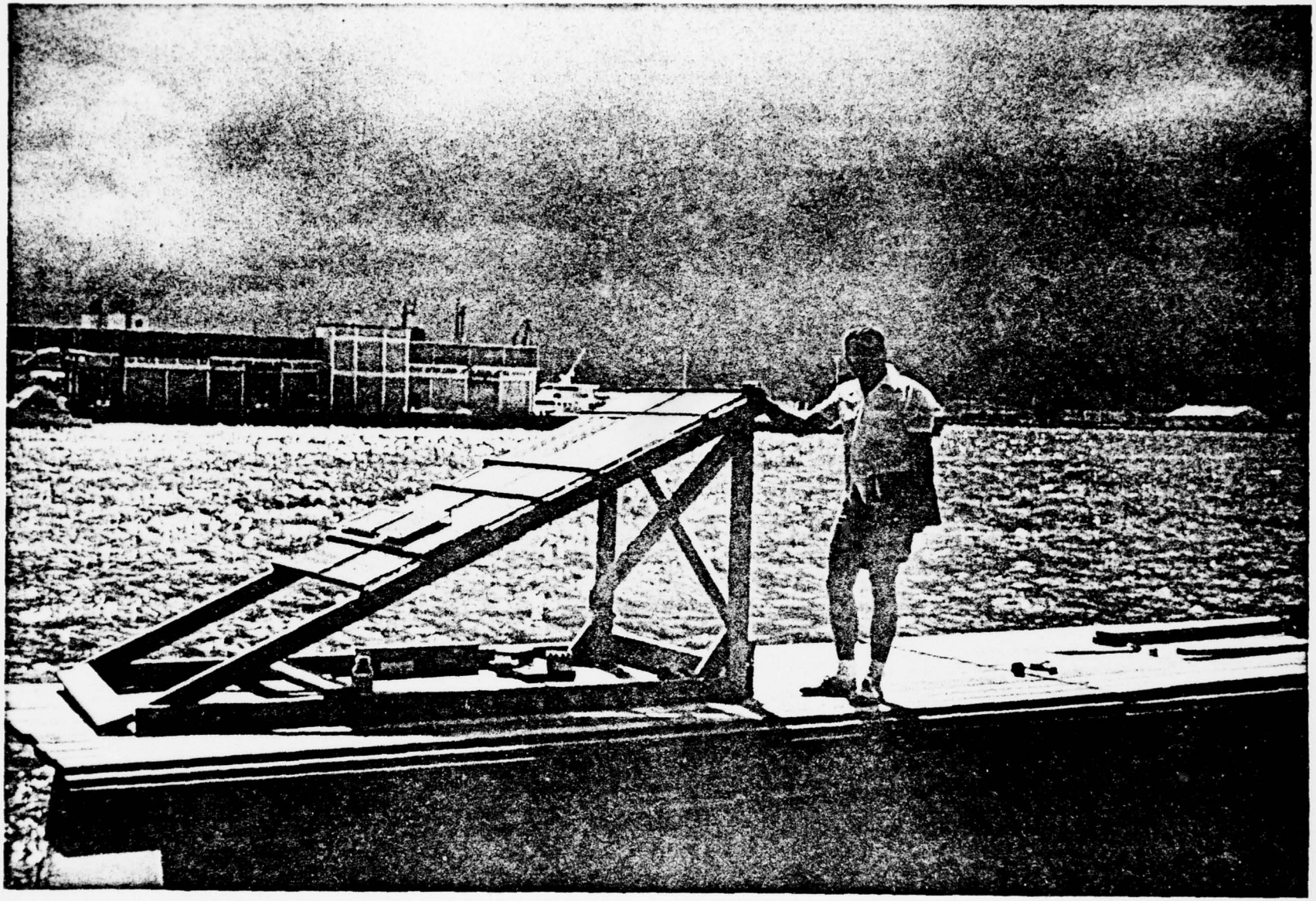

Figure 2-3. Mounting Stand. Tilted to the horizon facing sourth, the mounting stand affords maximum solar exposure.

TABLE 2.1 - ESTIMATED CLIMATOLOGICAL CONDITIONS FOR SOUTHERN MARINE EXPOSURE FACILITY

Weather Elements	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature												
Mean Temperature (^{o}C)	20.8	21.0	22.1	23.6	25.6	27.3	28.4	28.6	27.9	26.1	23.9	21.7
Mean # days with:												
Temperature $\geq 85^{o}F$	0.2	0.4	0.8	1.1	4.4	13.4	26.4	30.2	18.8	5.8	1.1	0.5
Temperature $\leq 32^{o}F$	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Relative Humidity												
Mean	74	75	75	74	77	79	78	78	79	76	74	73
Cloud Cover												
Mean # days with:												
Sky overcast or obscured	15.7	13.9	14.7	11.6	11.2	14.2	8.0	8.7	14.5	15.5	10.8	13.8
Mean Cloud Cover (Eights)	4.2	4.1	4.0	3.8	3.7	4.3	3.9	4.1	4.5	4.4	3.9	4.2
Precipitation												
Precipitation (inches)	2.9	2.6	2.0	1.8	2.7	3.7	2.3	2.8	4.4	4.3	2.6	2.5
Wind												
Mean # of days with:												
Wind ≥ 34 knots	0.8	1.6	0.5	0.1	0.2	0.4	0.1	0.2	1.9	2.0	0.7	0.8
Water Temperature												
Mean ^{o}C	21.7	22.1	23.3	25.1	27.1	28.8	30.1	30.3	29.3	26.9	24.4	22.6

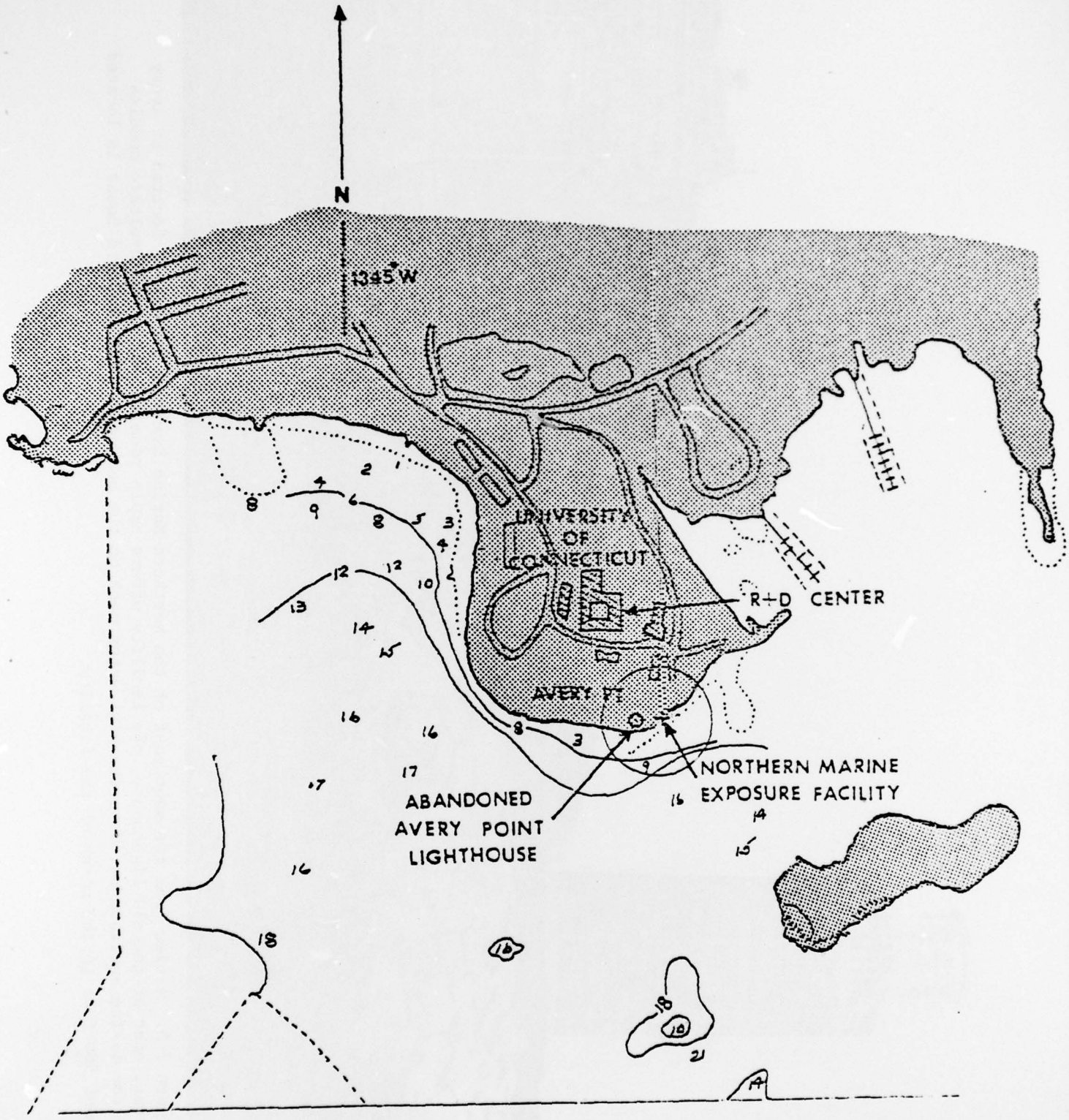

FIGURE 2-4. NORTHERN MARINE EXPOSURE FACILITY. THE FACILITY, LOCATED 75 FEET EAST OF THE ABANDONED AVERY POINT LIGHTHOUSE, ON AVERY POINT HAS A FINE SOUTHERN EXPOSURE TO LONG ISLAND AND FISHERS ISLAND SOUND.

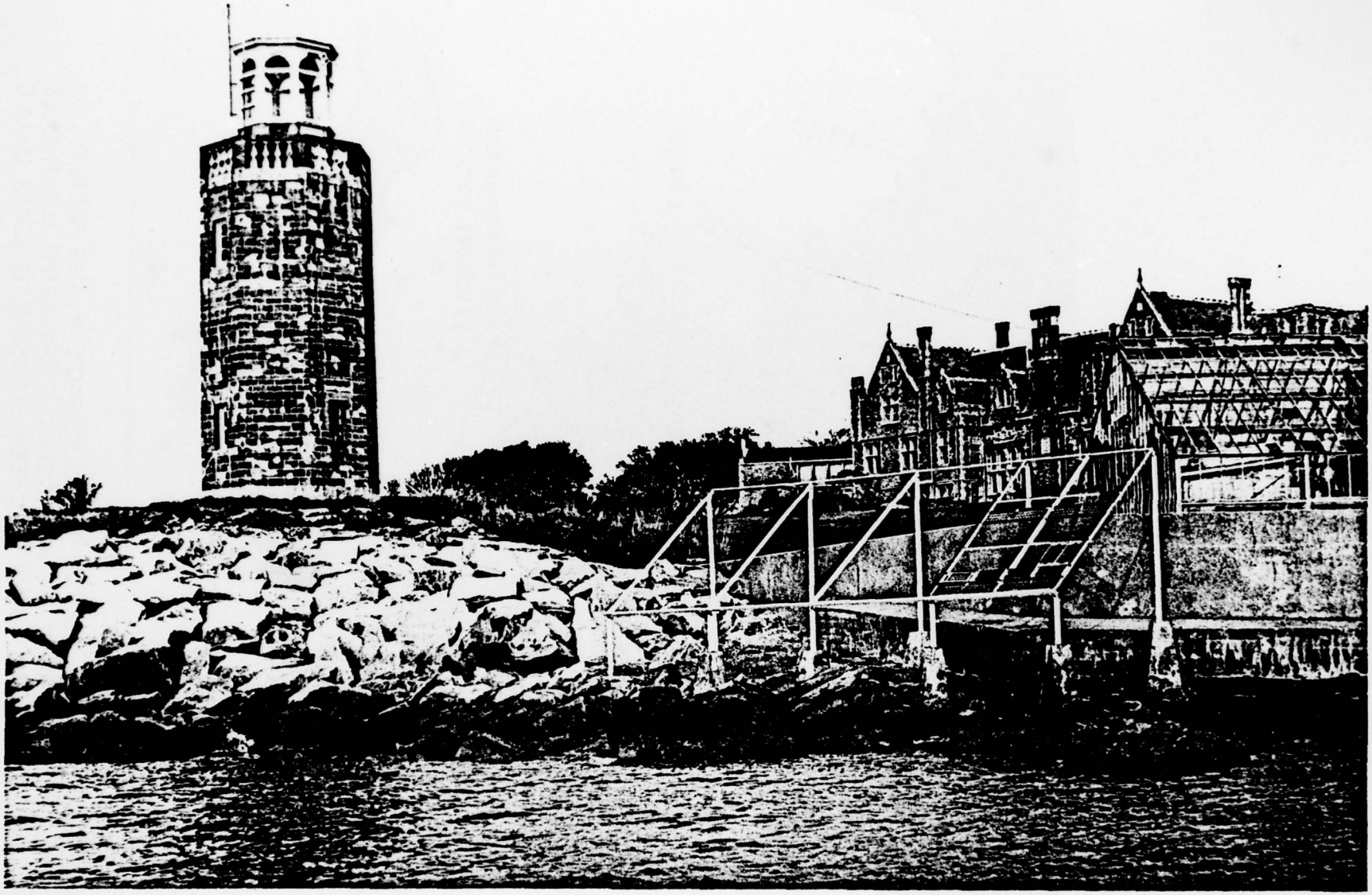

Figure 2-5. A view from the southeast of the Northern Marine Exposure Facility. Located at Avery Point, east of the old lighthouse, the facility offers ample room to expose photovoltaic modules to the marine environment. Note the high water mark on the bulkhead. The Branford House is located about 500 feet to the north of the facility.

The anticipated climate at the Northern Marine Exposure Facility is given in Table 2-2. The actual climate will be characterized by in-situ measurements as in case of the southern facility.

The modules will be mounted on L-angle and electrically loaded in the same fashion as at the southern facility.

TABLE 2.2 - ESTIMATED CLIMATOLOGICAL CONDITIONS FOR NORTHERN MARINE EXPOSURE FACILITY

Weather Elements	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Temperature Mean °C	-0.6	-0.6	2.8	8.3	12.8	18.3	22.2	21.7	18.3	13.3	7.8	1.1	10.6
Max Daily °C	2.8	2.8	6.1	12.2	17.2	22.9	25.5	25.0	22.2	17.2	11.1	5.0	14.4
Min Daily °C	-4.4	-3.9	-0.0	4.4	9.4	14.4	17.8	17.8	14.4	9.4	3.9	-2.2	6.6
Extreme lowest °C													35.0
Extreme highest °C													-19.4
Min 0° or less Mean No. of Days	24	24	18	4	0	0	0	0	0	0	7	20	95
Relative humidity													
Average Percent (0700*)	72	72	72	75	77	81	82	82	82	79	77	74	77
Average Percent (1300*)	62	62	62	61	63	63	65	65	65	62	63	64	64
Cloud Cover													
Mean # days w/clear skies	8	8	8	8	7	8	7	8	10	11	8	8	100
Mean # days w/cloudy skies	14	13	13	13	13	12	12	12	11	11	14	15	154
Average Amount (tenths)	6.3	6.1	6.1	6.3	6.3	6.2	6.4	6.2	5.8	5.5	6.5	6.2	6.1
Precipitation													
Mean Amount (inches)	3.1	3.1	3.7	3.4	3.4	2.3	3.1	3.8	3.0	2.8	4.1	3.8	40.0
Mean snow (inches)	6.0	7.1	5.8	0.4							.4	4.5	24.0
Mean # days w/snow 1" of more	2	2	2						2	7			
0.01 Inches of Pres Mean days	11	10	10	10	10	8	7	8	8	7	10	11	113
Visibility													
Days with Visibility > 0.25 miles	4	4	4	7	9	9	10	10	10	3	2	3	79
Water temperature													
Mean °C	2.8	2.4	4.3	9.3	14.3	19.2	22.1	22.5	20.3	16.2	10.9	5.5	12.5

*Local Standard Time

3.0 AUXILIARY USES OF THE MARINE EXPOSURE FACILITIES

In addition to the solar photovoltaic modules, a solar photovoltaic energy system is composed of several other components all of which must function flawlessly if the reliability of the entire system is to be assured. That is, a failure of the photovoltaic module, battery, regulator, connectors, or interconnect wiring will result in the failure of the entire system and extinguishing of the AN. Since some of these components are seriously affected by the marine environment, exposure testing must be performed to determine their reliability and what improvements might be instituted to increase their potential for survival. The marine exposure facilities offer an excellent platform from which to conduct these tests, and ample space exists at the northern facility to do so. Therefore, in the future, varied tests will be carried out. These will include (1) electric terminal corrosion, (2) battery terminal corrosion, and (3) zener diode reliability.

4.0 CONCLUSIONS

Two marine exposure test facilities have been erected. The southern facility is located at Coast Guard Station Fort Lauderdale, and the northern facility is located at the Coast Guard Research and Development Center, Avery Point. Both offer an excellent location from which to expose photovoltaics and other auxiliary system components to the marine environment. Both sites meet the original selection criteria, except that the northern site is less secure than desired. The method of construction and the materials used should prove both esthetically acceptable and rugged (i.e., adequate longevity for the proposed test period of less than six years).

The two sites offer the Coast Guard a unique facility to assess the reliabilty of solar photovoltaic energy systems components in the marine environment, and to generate data essential to determining their cost-reliability relations.

REFERENCES

1. Economic Analysis of Solar Energy for Minor Aids to Navigation, William Allen, 1978.

2. GSA Contract No. 005-64565 with OCLI (Optical Coating Laboratory Incorporated) (for Quantity of 25-49).

3. June 1978 Price Quotes from OCLI, Solar Power Corp., Sensor Technology, Motorola, Arco Solar (for Quantity of 25-49).

4. USCG R&DC Energy Sources Project Plan 792705 and NEET Experiment Plan. May 1978.